A PC-BASED RF TEST CONSOLE FOR INTEGRATION & TEST ON NASA'S LUNAR PROSPECTOR SPACECRAFT

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ABSTRACT

Lunar Prospector's project engineering staff selected a Windows PC platform as the RF test console for the Lunar Prospector spacecraft. The spacecraft test team chose the PC-based RF test console because the PC provides a low-cost, common platform with a graphical user interface. The PC provides point-and-click, menu-driven windows that are common throughout the satellite factory. The PC RF test console is being used to exercise the Lunar Prospector spacecraft RF link for RF commanding, telemetry, and ranging signals during factory test, including thermal vacuum chamber testing.

For spacecraft command and control at the factory, the PC-based RF test console is networked to a UNIX workstation over RS-422. The PC RF test console and spacecraft interface are controlled through a coax switch residing in a test rack next to the workstation. The PC RF test console is connected directly to the Lunar Prospector spacecraft using coax cable through the spacecraft Telemetry, Commanding, & Ranging (TC&R) RF antenna hat for both transmit and receive functions. The PC RF test console is also connected hard-line to the spacecraft transponder through the transponder RS-422 connection. This connection provides the ability for spacecraft telemetry to be received at the PC at RF or baseband. The same hard-line spacecraft telemetry data is provided to the UNIX workstation for comparison.

NASA's Lunar Prospector project is the first of the Discovery series of "faster, better, cheaper" missions to be competitively awarded. Lunar Prospector project funding was capped by NASA to ensure that no overruns would occur. The mission was funded to support the scientific community's desire to verify the presence of ice on the moon and collect environmental data to understand the dynamics that may have led to polar ice deposits. The Lunar Prospector mission received funding in 1996 with a launch planned for September 1997.

KEYWORDS

Lunar Prospector, Integration, Test, RF, Satellite, Commanding, Telemetry, GUI, Test Consoles, PC, Workstation, Ground Station, Mission Control, Mission Analysis, Analysis, Ranging

INTRODUCTION

The PC was created in 1984 when IBM contracted to a small company in the state of Washington to provide an operating system for a new desktop computer product. The operating system's name was DOS and was, in fact, used by IBM. The desktop PC has continued to evolve into a low-cost, commercial-off-the-shelf, high-performance platform for use as a general test tool. In the early 1990s, Telemetry & Instrumentation designed a telemetry quick-look capability using PC hardware and the DOS operating system. Proprietary displays were designed for display and analysis tools. When Microsoft released its Windows operating system, the PC quick-look product was ported to Windows.

In parallel to the quick-look telemetry system using DOS, a PC-based telemetry and command board set (TCBS) was designed with digital signal processing (DSP) technology for the Globalstar satellite constellation. The TCBS included demodulation, modulation, bit synchronization, and frame synchronization functions on a single DSP-based PC board. Two other PC boards included an RF receiver, RF transmitter, and upconverter and downconverter. One of the telemetry quick-look serial outputs was used as a command formatter and command modulator interface. Tone ranging and pseudo random noise (PRN) ranging systems were added on a PC board, which provided all the functionality of a satellite TC&R earth station. The PC board setup and control software was written using Windows and NT. Today, the TC&R PC uses either a tailored DSP TCBS group of DSP boards or third-party single-function PC boards to provide the desired functionality. Table 1 compares the different PC platforms for ground station applications.

SPACECRAFT FACTORY INTEGRATION & TEST

The PC RF test console was chosen for Lunar Prospector spacecraft integration & test (I&T) activities because of its ability to transmit and receive at RF and over an RS-422 spacecraft transponder interface. The PC was connected to the UNIX workstation, which was part of the test equipment. (The PC receives telecommands over RS-422 from the workstation and sends frame-synced telemetry back to the workstation for simultaneous decommutation. The PC receives formatted commands over RS-422 from the UNIX/OASIS test executive software, converts them to RF, and transmits them through the coax cable and spacecraft antenna hat.)

Table 1. Comparison of PC Capabilities

Function	DOS	Windows	NT	TCBS
Commanding	None	<100 kbps	<100 kbps	<1 kbps
Modulation Types	None	PM, FM	PM, FM, QPSK, OQPSK, Spread Spectrum	FM
Carrier	None	PM, FM	PM, FM	FM
Subcarriers	None	< 1 MHz	< 1 MHz	None
Ranging	None	Tone, PRN	Tone, PRN	None
Location of Data	None	Carrier, Subcarrier	Carrier, Subcarrier	None
Demodulation	None	PSK	PSK, FSK	None
Telemetry	< 10 Mbps	< 20 Mbps	< 50 Mbps	< 10 kbps
Modulation Types	PM, FM	PM, FM	PM, FM, QPSK, OQPSK, Spread Spectrum	FM
Network	RS-232, RS-422	Ethernet, RS-232, RS-422, IEEE-488	Ethernet, RS-232, RS-422, IEEE-488	None

The Lunar Prospector technical team's goal was to exercise the spacecraft's RF link prior to NASA's ground station RF compatibility test. NASA's compatibility test van (CTV) runs RF test procedures on each NASA mission to verify spacecraft and ground station compatibility. The Lunar Prospector technical team wanted RF command, ranging, and telemetry receiving links exercised during both ambient and thermal vacuum test to prepare the spacecraft for NASA's compatibility testing. For all tests, the PC was networked to an HP workstation running UNIX spacecraft test software. The UNIX software was networked to both the Lunar Prospector spacecraft through the spacecraft transponder's RS-422 hard-line interface and to the PC. Spacecraft commands were sent to the PC, and frame-synced telemetry was routed to the workstations via RS-422. The test & integration configuration for Lunar Prospector is shown in Figure 1.

The PC RF test console was maximized by using the RF link for ambient testing before, during, and after thermal vacuum testing. The Lunar Prospector test team also used the RF link during thermal vacuum environmental testing. RF telemetry and commands were sent in and out of the thermal vacuum chamber through the chamber plate interface as shown in Figure 2.

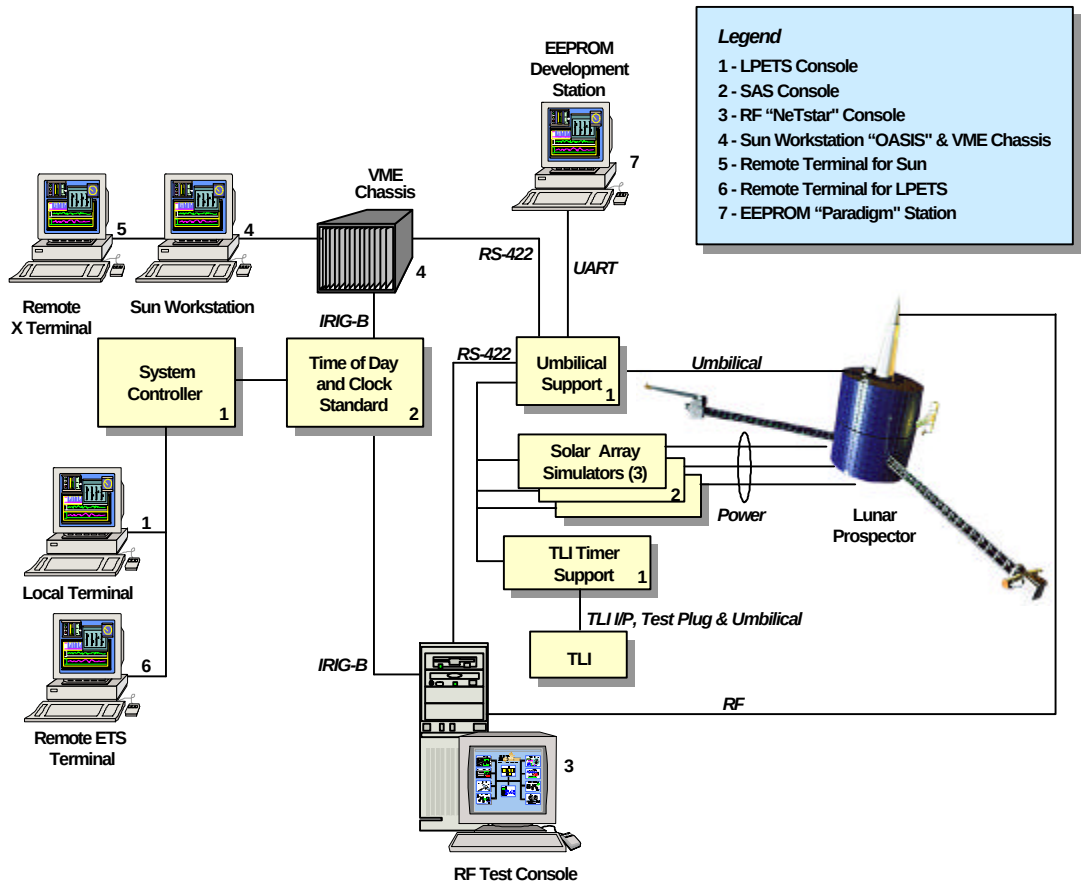

Figure 1. Lunar Prospector I&T Test Equipment

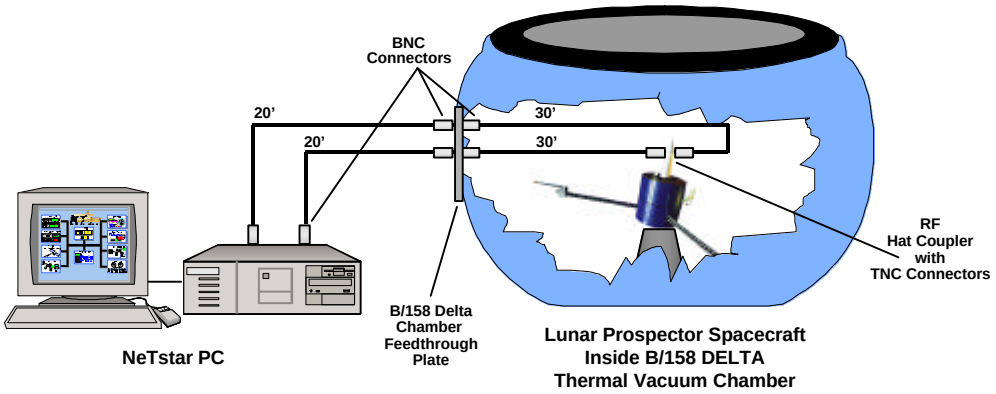

Figure 2. Lunar Prospector Thermal Vacuum Chamber Configuration

Table 2 identifies Lunar Prospector's I&T interfaces and Telemetry, Commanding, & Ranging (TC&R) subsystem parameters.

Table 2. Lunar Prospector Spacecraft I&T Interface Characteristics

Telemetry D/L		Command U/L	
Network Interface	RS-422	Network Interface	RS-422
Receive RF Carrier Frequency	2273.0 MHz	RF Uplink Frequency	2093.0 MHz
Intermediate Frequency	70 MHz	Carrier Modulation	PM
Demodulator Input	70 MHz	Subcarrier Offset	16 kHz
Demodulator Output	300 & 3600 bps	Subcarrier Modulation	BPSK
Bit Sync Input	300 & 3600 bps	Bit Rate	250 bps
Viterbi Decoding	Rate ½, K=7	Command Word Length	32
Code Conversion	NRZ-L to NRZ-M	Internal Execute /Execute Tone	Internal
Data Rates	300 & 3600 bps	Number of Commands	39
Number of Telemetry Measurements	~300	Receiver Carrier Threshold	TBM
Carrier Modulation	Phase Modulation	Command Receiver Threshold	TBM
Number of Subcarriers	1	Restricted Commands	0
Subcarrier Offset	1.024 MHz	Block Commands	0
Subcarrier Modulation	BPSK	Serial Magnitude Commands	~13
Analog Measurements	~50	Number of Pulse-Type Commands	~58
Digital Measurements	~250	Number of Relay-Type Commands	~32
		Number of Execute Commands	1
Ranging Systems			
Ranging Types	Tone, PRN	PRN Rate	1 Mbps
Number of Tones	4	Tone Frequencies	STDN

PC HARDWARE FOR LUNAR PROSPECTOR

PC Telemetry Receiver/Demodulator

The Lunar Prospector PC Telemetry Receiver/Demodulator receives an S-Band RF signal, phase-demodulates the carrier and PRN ranging tones (when present), downconverts the demodulated carrier to IF, and demodulates the 1.024 MHz subcarrier with telemetry for either real-time 3.6 kbps fast or 300 bps slow data. The demodulated PRN ranging and telemetry data is sent to separate bit synchronizers for timing and correlation. The PRN range tones are modulated on the S-Band carrier. The 4-tone ranging data is modulated on the subcarrier. The demodulated range tones are output to the range processor for phase measurement and range delay calculation and display. The telemetry data is output to the decommutator for frame synchronization and local decommutation. The frame-synced data is also transferred to the workstation software over the RS-422 interface for final decommutation, display, and analysis.

PC Telemetry Bit Synchronizer

The Telemetry Bit Synchronizer receives demodulated telemetry and synchronizes a clock to the incoming PCM data stream. A Viterbi decoder decodes rate ½, constraint length

K=7 encoded data with eight combinations of connection vector swapping and alternate symbol inversion. The bit synchronizer outputs clock and data for frame-syncing, archiving, and data decommutation.

PC Decommutator

The Telemetry Decommutator receives a serial data stream and clock from the bit synchronizer. The decommutator's maximum rate is ~20 Mbps NRZ-L PCM with 32K words per frame. It provides frame and subframe sync functions and serial outputs for frame sync data transfer to the workstation.

PC Command and Range Tone Modulator

The Command and Range Tone Modulator modulates a command message and range tones onto the appropriate carrier or subcarriers from inputs controlled by the command and range software. A Command module receives a TTL input from the command system. The output of the modulator is a complex IF signal consisting of modulated command and range tones on a 70 MHz signal output to the upconverter.

PC PCM Simulator

The PCM Simulator generates a user-defined PCM stream that can exercise frame/subframe modes of processing. Alternatively, the user can take advantage of a set of predefined wavetrains selectable through a point-and-click user interface. A PCM wavetrain is available for self-test.

PC Time Code Reader and Generator

The Time Code Reader and Generator is used for setup and checkout prior to use, and for self-diagnostic routines. It independently provides a tool for time-stamping, diagnostics, and data redistribution. The time capture is triggered by a pulse (event signal). Time-stamping is done every minor frame or once per data buffer.

PC Command Interface

The Command Interface selects the command and generates the command message in the proper format. The complete command message goes to the command modulator at TTL for modulation onto a custom-configured signal. The command database can be imported through spreadsheet-type applications, ASCII, or directly from a floppy disk.

PC Upconverter and Power Amplifier

The Upconverter interfaces with the Command and Range Tone Modulator to receive a complex 70 MHz signal. The signal is upconverted to S-Band at RF. The S-Band power amplifier provides a low-level RF signal based on the modulated signal from the Command and Range Tone Modulator board, and interfaces with the Lunar Prospector RF antenna hat through a coax cable and connectors. The RF signal includes a command carrier, a subcarrier, carrier range tones, and subcarrier range tones.

PC WINDOWS NT SOFTWARE

The Windows operating system for the PC RF test console provides a graphical user interface for hardware and software setup and monitoring, data archiving, and real-time data acquisition, command generation, and ranging. Windows uses an intuitive, graphical point-and-click and menu-driven interface for configuring and monitoring all the system's hardware and software packages. The PC satellite command and control software runs in Windows and has the same user interface characteristics.

The Lunar Prospector test team is using the PC for real-time and post-pass data acquisition, analysis, and archiving capabilities in a PC workstation environment where data can be distributed from a server to multiple clients. The system features nine different display tools for data analysis and display, including horizontal bar charts, vertical bar charts, strip chart recorders, oscilloscopes, text-range displays, tabular text displays, scrolling text, alarm loggers, and dials.

The software features a Heartbeat Page, shown in Figure 3, that launches the user into system functions through a point-and-click interface. The Heartbeat Page also provides quick status of selected parameters and functions. It is reconfigurable to display all or only a subset of available functions.

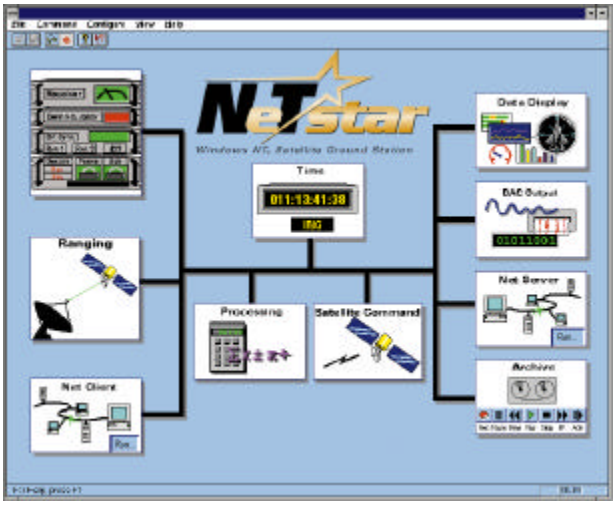

Figure 3. The PC Console's Reconfigurable Heartbeat Page

Figure 4 is an example of a screen display that can be produced using the PC's telemetry display and analysis tools.

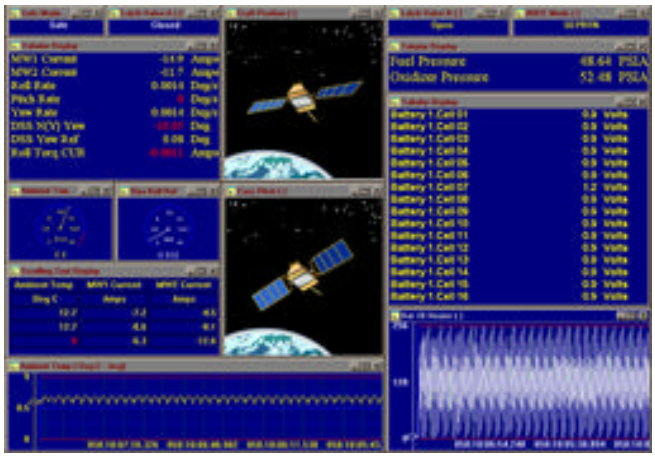

Figure 4. Telemetry Display Page

PC Command Software

The system's Command Software stores the satellite command database and formats a command by adding the appropriate header. It is used for local and standalone test, and system checkout. Commands that require real-time generation are executed by using the editing function and third-party algorithms.

PC Ranging Software

The PC Ranging Software calculates the distance from the PC RF console to the satellite and determines the distance to the satellite based on the round trip time delay of a range tone/PRN bit stream. Ambiguity is resolved by using several tones. A PRN code is also used to determine the round trip time from the console to the satellite for use with deep space missions. The system's PC ranging tones can be made compatible with NASA's Deep Space Network (DSN) tone ranging system.

PC NETWORKING

The PC RF test console uses industry-standard interfaces to transmit and receive data and commands. The workstation is networked to the PC using RS-422. The PC, too, is networked to the spacecraft using RS-422. A serial RS-232 port is used to send networked commands to the spacecraft over coax. The inherent designed-in features of multiple I/Os allow for networking in a LAN or WAN for data transfer across the network or for archival. Other network interfaces available for the PC include IEEE-488, MIL- STD-1553, Ethernet, and TCP/IP.

CONCLUSION

Telemetry & Instrumentation's PC RF test console combines the proven, easy-to-use, common, open architecture of the PC with the needs of satellite designers, builders, and operators worldwide. A PC running Windows can provide all the command, telemetry, and ranging capabilities necessary for completing spacecraft factory integration & test. A PC RF test console can operate as a standalone unit or be networked to a workstation environment and legacy test equipment. The Lunar Prospector test team lowered costs and complexity, and increased test team efficiency by using a PC RF test console for spacecraft factory testing.

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